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WATER-HEAT REGIME OF EARTH CATCHWORK DAMS (ZEMLYAN'KH PLOTIN LM--ETC(U)  
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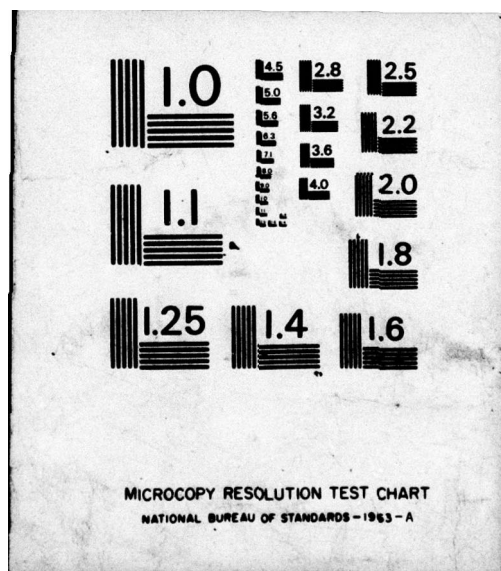
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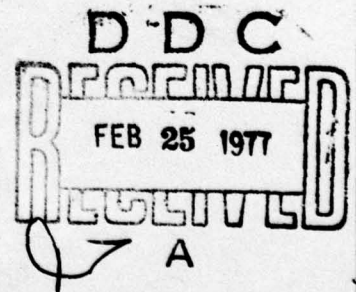
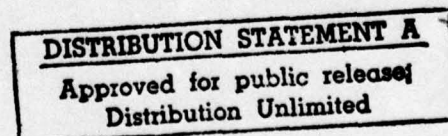


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# WATER-HEAT REGIME OF EARTH CATCHWORK DAMS

R.V. Chzhan



CORPS OF ENGINEERS, U.S. ARMY  
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY  
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### **WATER-HEAT REGIME OF EARTH CATCHWORK DAMS**

**Yakutsk TRUDY YAKUTSKOGO NAUCHNO-ISSLEDOVATEL'SKOGO INSTITUTA SEL'SKOGO KHOZYAYSTVA in Russian No 12, 1972 pp 93-101**

[Article by R. V. Chzhan, Institute of Permafrost Studies of the Siberian Department of the USSR Academy of Sciences]

[Text] The geocryological conditions of operation of the irrigation system dams of Central Yakutia differ sharply from their leveled regime. Using this characteristic all the land improvement dams may be divided into two groups:

1. dams with permanent, year-round pools;
2. periodic dams, which hold water for no more than 1-1.5 months in the spring and summer when the pools they form fill.

The planning of earth dams in Far North regions involves heat engineering calculations which make it possible to draw up the necessary geocryological prognosis of the heat regime of the grounds of the dam and its foundation during the period of use.

A methodology of such prognoses for dams of the first type, permanent pool dams, has been developed and is used in engineering practice. But dams of the second type, the seasonal pool dams which are ordinarily used for irrigation in Central Yakutia, are planned without geocryological calculations.

In view of the large-scale deterioration of catchwork dams in Yakutia, the Institute of Permafrost Studies carried out a special investigation to identify the causes of dam deformation and propose some ways of preventing them. Some results of this research are set forth in this article.

The geocryological investigation included a cycle of regime observations at operating sites and a calculation of the change in the temperature fields of dams during the period of operation. Two land improvement systems were chosen for on-site observation: the Khorobutskaya system,



whose structures have an established (steady) temperature regime, and a new system on the Khos-Yurekh River in Gornyy Rayon.

#### The Korobutskaya Land Improvement System

The system runs along an ancient terrace above the floodplain of the Suoly River. The terrace is composed of strongly iced Quaternary deposits. The irrigated lands of the system are set on the floor of thermokarst basins which have weakly iced loams up to six meters thick on top and unsorted sand beneath. Permanently frozen rocks reaching thicknesses of 300 meters are continuous. Shallow taliks are found in alassy and beneath thermokarst lakes. The temperature of permafrost grounds at the depth of zero annual fluctuations is  $-2$  degrees. The depth of seasonal thawing varies from 1.6 to 2.0 meters in the irrigated meadows.

The land improvement system was built in 1959-1965. After the flood waters of 1964 and 1965 were passed through as tests the system was turned over for operation in 1966. The structures include the main intake, the trunk canal, and four backwater regulators. Earth dams up to 3.0 meters in height and 6.0 meters across the crest were poured using powdery heavy local loams with humidity of roughly 35 percent. The ground was put into the body of the dam by scrapers and compacted until the skeleton had a volumetric weight of 1.5 grams per cubic centimeter. A 0.2-0.5 meter layer of sand-chipped rock was poured on top the dam profile.

The program of on-site geocryological observations included:

1. an annual cycle of ground temperature measurements through 26 boreholes 10-20 meters deep drilled from the crest of the dams, their slopes, pools, and near the wiers;
2. detailed observations of the rate of thawing and change in temperature of the seasonally thawed layer of grounds;
3. observations of change in the moisture level of the grounds of the seasonally thawed layer for the same period as in No 2 above;
4. measurement of water temperature in the pool area near the dams.

In addition, a monthly snow survey was made on the dams and, using a square grid with 27 meter sides, near them; snow density was analyzed and a weather diary kept.

The results of geothermal observations illustrate that the thermal regime of the dams stabilized completely in a period of six years. Seasonal thawing in the crest in the sections with heights of 3.4 and 2.3 meters was 0.7-1.0 meters during the period of pool filling. By the time of water release on 15 June 1970 the thawing had developed to 1.15 meters; by the end of autumn it had reached a depth of 2.6 meters, which means that the dam was almost completely thawed. At the depth of zero annual

amplitudes (15 meters) the temperature year-round was -2 degrees, close to the temperature of permafrost grounds under undisturbed natural conditions.

In heat engineering calculations for dams the moisture level and density of the grounds are always assumed to be unchanged during the period of operation of the dams. Observations of the Khorobutskaya dams showed that the moisture level of the grounds in the central part of the dams studied decreased from an initial value of 25-35 percent in 1965 to 15 percent in 1970 (see Figure 1).

A large range of moisture fluctuations was also recorded in the seasonal thawing layer of the dam profile. The influence of the orientation of the slopes relative to light on change in ground moisture levels should also be noted. Drying out is 3-5 percent more intensive on south-facing slopes than on slopes facing north. This effect is observed even when the south-facing slope is the upstream slope and is moistened during pool filling.

#### The Land Improvement System on the Khos-Yurekh River in Gornyy Rayon

The valley of the Khos-Yurekh River is 19 kilometers long and ranges in width from 150 to 500 meters. It passes along the eastern slope of the ancient alluvial plain of the Lena-Vilyui interfluve. Quaternary beds in the stream valley are represented by various sandy loams and loams up to 10 meters thick containing occasional ice and ice-ground veins. On the walls of the valley the thickness of the modern ice-ground complex reaches 2-3 meters and residual ice-ground forms are found in the depth interval 2-8 meters.

Permafrost rocks occur in a continuous stratum up to 350-400 meters thick. Their temperature at a depth of 15 meters, in the zone of zero annual amplitude, is -3 degrees in the valley and on its southern slope. On the northern slope of the valley the temperature of the permafrost rocks is -5 degrees. Under differing landscape conditions the summer thaw varies from 0.4 to 2.0 meters.

Most of the water-raising structures of the land improvement system were built in the summer of 1968. In that year five dams up to 3.5 meters in height and five levees up to 1.5 meters high were built and one dam and one levee built four years earlier were rebuilt. The system also includes the trunk canal, 18 kilometers long, connecting the pools.

The dams and levees were made of local sandy loam and loam material set in the bodies of the dams by bulldozers and compacted to volumetric weights of 1.2-1.4 grams per cubic centimeter with a moisture level of 50-60 percent. The crests and slopes were left unprotected.

The program of observations on the Khos-Yurekh system was similar to the program in the Khorobut region. To avoid repetition we will cite only a few results which supplement the data obtained from Khorobut.



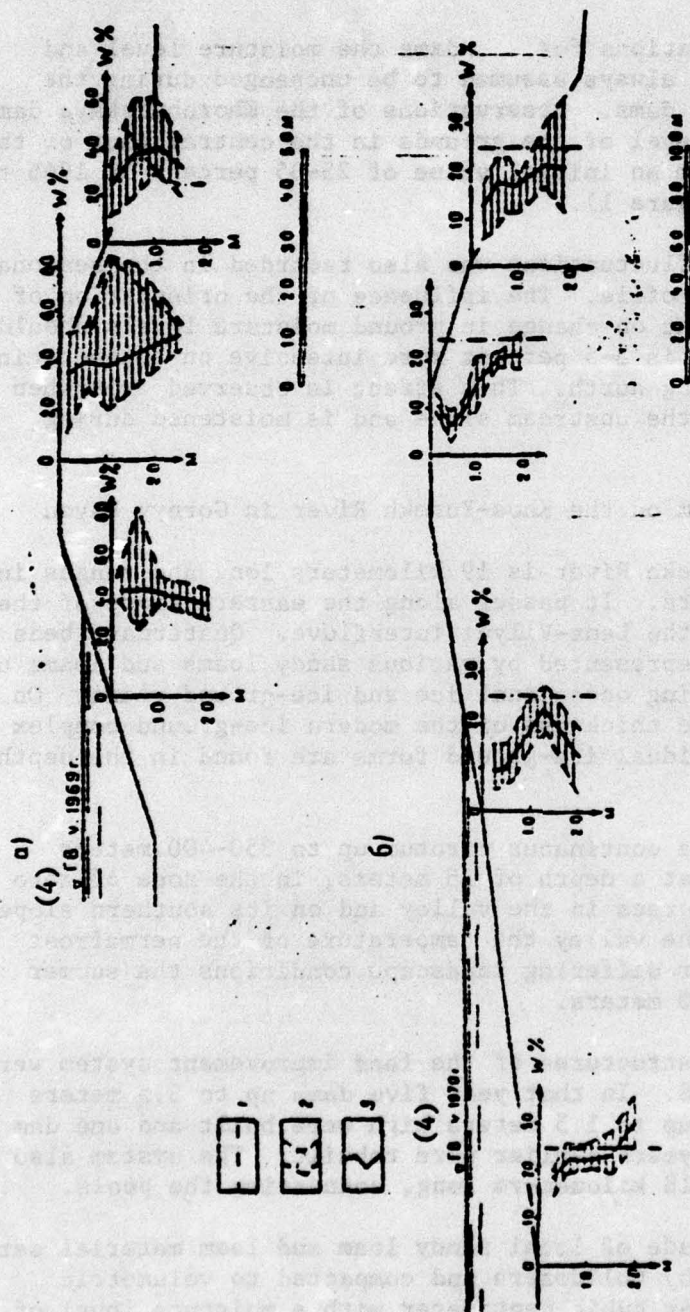


Figure 1. Change in the Moisture of the Ground: a) in the Body of Dam No 1 on the Khos-Yurekh River in Gornyy Rayon of the Yakut ASSR During Two Years of Operation (1968-1970); b) in the Body of the Main Regulation Dam of the Khorobutskaya Land Improvement System on the Suoly River of Megino-Kangalasskiy Rayon of the Yakut ASSR in the Summer of 1970.

Key: (1) Initial Distribution of Moisture;  
 (2) Change in Moisture;  
 (3) Average Moisture;  
 (4) Water Level.

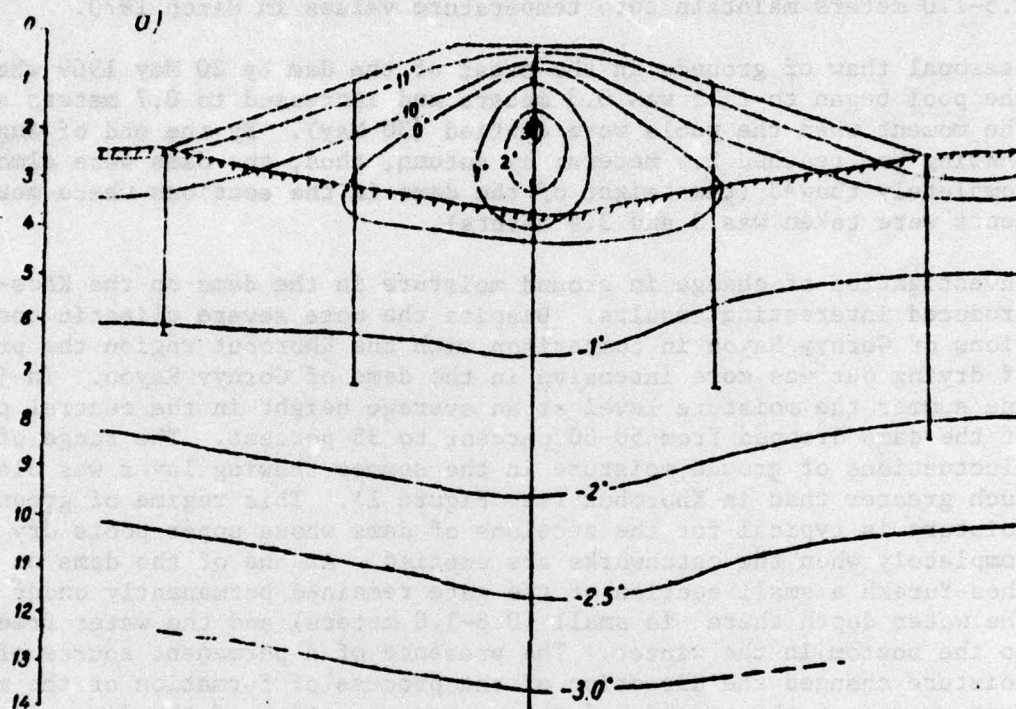
The results of geothermal observations at the Khos-Yurekh dams showed that they froze to the foundation in the first winter (see Figure 2). Only in the lower part along the axis of the dam did a small layer of 0.5-1.0 meters maintain zero temperature values in March 1970.

Seasonal thaw of grounds in the crest of the dam by 20 May 1969 when the pool began to fill was 0.3 meters and increased to 0.7 meters at the moment when the pools were emptied (30 May). By the end of August thawing had reached 2.4 meters; by autumn, thus, the dams were almost completely thawed (the height of the dams in the sections where measurements were taken was 3 and 3.4 meters).

Investigation of change in ground moisture in the dams on the Khos-Yurekh produced interesting results. Despite the more severe climatic conditions of Gornyy Rayon in comparison with the Khorobut region the process of drying out was more intensive in the dams of Gornyy Rayon. In just one summer the moisture level at an average height in the central part of the dams dropped from 50-60 percent to 35 percent. The range of fluctuations of ground moisture in the summer thawing layer was also much greater than in Khorobut (see Figure 1). This regime of ground moisture is typical for the sections of dams whose upper pools dry up completely when the catchworks are emptied. At one of the dams on the Khos-Yurekh a small section of the gate remained permanently under water. The water depth there is small (0.8-1.0 meters) and the water freezes to the bottom in the winter. The presence of a permanent source of moisture changed the direction of the process of formation of the moisture regime of the grounds of the upstream section of the dam. In this section the average moisture of the ground did not decrease during the summer; it increased, going from 40 to 60 percent. At the same time the grounds on the downstream side, without a permanent source of moisture, dried out and by autumn their moisture level had dropped from 40 to 30 percent.

The characteristic features of the moisture regime of the grounds of low-head earth dams in Central Yakutia were determined in the experiment: dessication of the grounds within the layer of seasonal thawing and freezing and significant fluctuations in ground moisture level in this layer during the summer are accompanied by the development of stresses which often reach the limit of the ground's tensile strength. When this limit is passed deformation of the ground occurs. Shrinkage cracks form in the dam and local subsidences develop. We observed the development of shrinkage cracks during the summer to be most intensive on the Khos-Yurekh dams. At the head dam of the system, for example, such cracks began to develop in June 1969 after the water from the pools was released. They developed most in the summertime; the three-meter dam was broken by a large number of parallel longitudinal cracks running along the crest and slopes of the dam. By 1 September were 10-15 centimeters wide on top and went to depths up to 1.4 meters; in other words, they passed completely through the thawed ground (see Figure 3). With the arrival of the first freezing weather the cracks offered paths for cold air to penetrate into





**Figure 2. Temperature Field of the Grounds of the Body and Foundation of Dam No 1 on the Khos-Yurekh River in Gornyy Rayon of the Yakut ASSR: a) in October 1968; b) in March 1969.**

**Key:** (1) Isotherm;  
 (2) Snow Cover;  
 (3) Natural Ground Surface.



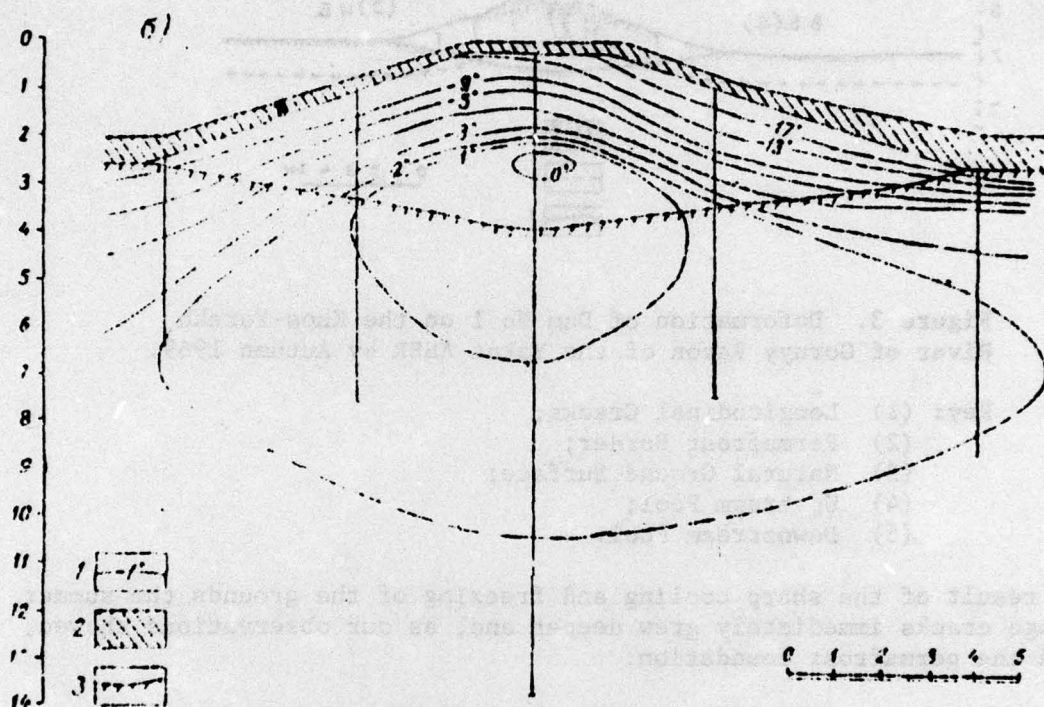


Figure 2. Temperature Field of the Grounds of the Body and Foundation of Dam No 1 on the Khos-Yurekh River in Gornyy Rayon of the Yakut ASSR: a) in October 1968; 6) in March 1969.

- Key: (1) Isotherm;  
(2) Snow Cover;  
(3) Natural Ground Surface.

the dam. The effect of such cooling was seen within a few days: the grounds of the seasonal thawing layer in the central part of the dam dropped to a temperature of  $-4$  to  $-5$  degrees to a depth of 2-2.5 meters.

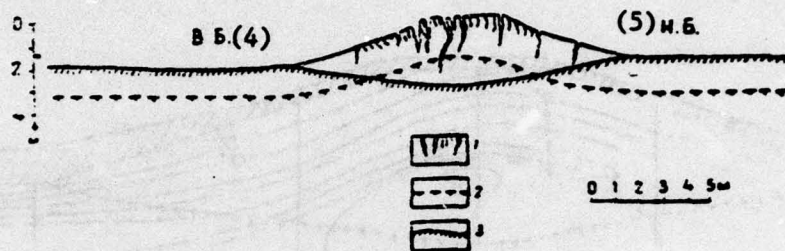


Figure 3. Deformation of Dam No 1 on the Khos-Yurekh River of Gornyy Rayon of the Yakut ASSR by Autumn 1969.

- Key: (1) Longitudinal Cracks;  
 (2) Permafrost Border;  
 (3) Natural Ground Surface;  
 (4) Upstream Pool;  
 (5) Downstream Pool.

As the result of the sharp cooling and freezing of the grounds the summer shrinkage cracks immediately grew deeper and, as our observations showed, reached the permafrost foundation.

Summer shrinkage deformation of the grounds was found in the dams of the Khorobutskaya system in the form of local subsidences in sections near the wiers. Longitudinal cracks did not develop in these dams, apparently because a protective sand-gravel cover was put on the surface of the dams.

Our observations of operating dams and the results of hydrothermal modeling enable us to draw the following conclusions:

1. The moisture level of the grounds drops significantly during the operation of catchwork dams. This process occurs in the summer, after the water has been released;
2. Aside from the general tendency toward a decrease in the ground moisture during the period of operation there are significant fluctuations in moisture level during the summer; the range of such fluctuations at a depth of 1-2 meters reaches 40-50 percent;
3. The general drying out of the seasonal thawing layer and the large range of moisture fluctuations in the summer lead to the development of stresses and



shrinkage deformation in the ground. During our observations we recorded numerous instances of such summer deformation in the form of cracks and subsidences;

4. The formation of summer shrinkage deformation in dams can be reduced or prevented by covering them with material which has a low shrinkage and swelling factor (sand, chipped rock, gravel);

5. According to our calculation of the temperature fields of the catchwork-type dams under consideration using the hydrothermal analogies method the thermal regime stabilizes in 4-5 years. The calculation data match data from observations on the Khorobutskaya land improvement system: the temperature fields of the dams stabilized in five years of operation.

6. When calculating the temperature fields of catchwork dams the dessication of grounds during the process of operation, which leads to an enlargement of the seasonal thawing layer, should be taken into account.

The theory of heat transfer by conduction is not applicable for predicting the thermal regime of dams subject to summer deformation (shrinkage from dessication) or deformation during the winter (frost cleft cracks).